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A Case Study of Efficacy of Freshwater Immersion in Controlling Introduction of Alien Marine Fouling Communities: The USS *Missouri*[1]

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ABSTRACT: The historically significant battleship USS *Missouri* was recently decommissioned and moved from Bremerton, Washington, to Hawai'i to become a memorial museum at Pearl Harbor, O'ahu, Hawai'i. Dry-docking was completed in January 1993, and since that time the vessel has been part of the inactive fleet. In this 5-yr period, a dense growth of fouling organisms had developed on the outer surfaces of the hull. Out of concern that the fouled hull could become a source for the introduction of alien aquatic nuisance species to Hawaiian waters, an evaluation of the fouling community was conducted. In this study we found 116 taxa among 12 phyla in 10 samples scraped from the vessel's hull. Seventy-six species were identified: 11 known from Hawaiian waters, 17 with known temperate-boreal distributions, and the remaining 48 known only from the Pacific Northwest. Forty percent of the taxa in this fouling community were not identified to species, so there remained some potential for alien species introduction. As a precaution to prevent accidental introductions, the ship was moved from Bremerton to the Columbia River in Oregon for a 9-day sojourn in freshwater before its transoceanic crossing to Pearl Harbor. Inspection of the vessel's hull upon arrival in Pearl Harbor revealed more than 90% of the hull to be completely clear of any fouling organisms. Only 11 species were found to be alive: 3 species probably recruited to the hull on the transoceanic crossing that may routinely arrive in Hawaiian waters, 4 species already present in Hawai'i, 3 Pacific Northwest species that appeared to be close to death on their arrival in Hawai'i, and 2 euryhaline amphipod species probably recruited to the hull while in the Columbia River. The amphipods were not reproductive and brooding young, suggesting that these species would not be successful colonists. A final inspection and sampling of the hull 83 days after arriving at Pearl Harbor failed to find live or dead Columbia River amphipods nor were the three Pacific Northwest species alive. Freshwater exposure for 9 days coupled with increased water temperatures during the journey to Hawai'i appear to be an extremely effective means of eliminating the temperate marine fouling community. This action substantially reduced the probability that an alien species would be introduced with the arrival of this historic vessel in Hawai'i.

THE HISTORICALLY SIGNIFICANT battleship USS *Missouri* was recently moved from Bremerton, Washington, to Hawai'i to become part of the memorial museum at Pearl Harbor. The surrender of Japan to the Allied Forces, made on the deck of the *Missouri,* brought closure to World War II in 1945. Dry-docking and painting of the hull were completed in January 1993 and until May 1998 she was berthed with the inactive fleet in the Naval Shipyard at Bremerton, in Puget Sound. During this period of time a dense

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community of benthic marine invertebrates developed on the outer surfaces of the vessel's hull. Ballast water tanks remained empty after dry-docking, and potential sources for alien species introduction were thus restricted to the fouling organisms on the outer surfaces of the hull. Concern was raised over the possible introduction of alien marine invertebrates to Hawai'i from these well-established fouling communities on the hull with the relocation of the *Missouri* from Puget Sound to Pearl Harbor.

Human-mediated transport of nonindigenous species has occurred for hundreds of years. Ships have carried many marine species across oceans attached to their hulls, but there has been little documentation of the impact of these early introductions (Allen 1953, Carlton 1987). Studies in San Francisco Bay show that barnacle introductions were under way by the 1850s (Carlton and Zullo 1969). Many introductions were made intentionally (e.g., the transplantation of oysters to grow for food [Carlton 1979, Kay 1979]). Cryptic and commensal species were often overlooked and transported with the oysters, and these species likewise became established (Carlton 1979, Bailey-Brock 1990). All of these activities resulted in a cryptogenic harbor-dwelling biota, with many of the same species occurring in ports with similar climates around the world (Carlton 1996). In the last 20 yr the number of successful introductions has greatly increased and this wave of invasions has been linked to ships' ballast water (Carlton 1985), which may carry a rich diversity of meroplankton and holoplankton. On a global scale ships' ballast water transports more than 3000 species on a daily basis (Carlton and Geller 1993). Many of these invasions have been documented (Coles et al. 1997), but introductions continue unabated.

The Hawaiian Islands are the most isolated archipelago in the world, with the closest major land mass (North America) lying more than 4300 km away. Before European discovery of the Hawaiian Islands, colonization of the Hawaiian marine environment was by natural (passive) means (Jokiel 1990) or occasionally via Polynesian voyaging canoes. In the last 75 yr Hawai'i has become a major crossroads for transpacific shipping. This has greatly increased the opportunity for successful colonization by marine species in Hawaiian environments from other distant places; Carlton (1987) estimated that 25 to 28 western Pacific and two Pacific coast species had been successfully introduced into Hawaiian waters by the mid-1980s. There are approximately 6500 known marine species from the Hawaiian Islands, of which about 1100 are considered to be endemic (known only from Hawai'i [Allison et al. 1995]). It is estimated that more than 150 marine and brackish-water species now in Hawai'i are introduced or cryptogenic; the majority are sponges, polychaetes, mollusks, crustaceans, and bryozoans (Coles et al. 1997).

The luxuriant growth of marine fouling on the hull of the *Missouri* raised concerns over the possibility that unwanted alien species would be introduced to Pearl Harbor. A three-phase study to address these concerns was undertaken by different parties to determine if such introductions would occur. In the first phase, marine communities on the *Missouri*'s hull were sampled while at Bremerton in Puget Sound and organisms were identified to the lowest possible taxonomic unit. The species list served as the basis for the second phase of the study, which was to determine the probability of species introductions occurring if the *Missouri* were to be towed from Puget Sound to Pearl Harbor with the fouling community intact on her hull. Because many taxa were not identified to species, it was impossible to determine if each taxon was present in Hawaiian waters. To avoid unwanted introductions from occurring, we suggested that the vessel be towed to the Columbia River for a period of exposure to freshwater with the intention of reducing the marine fouling before being towed to Pearl Harbor. The third phase of this study was inspection of the vessel's hull to determine the condition of any fouling remaining on the hull at the time of arrival and again 83 days after its berthing in Pearl Harbor.

MATERIALS AND METHODS

The initial sampling of the fouling community on the hull of the *Missouri* was carried out at Bremerton, Washington. Ten 0.1-m^2 samples were scraped from the stern, propeller, rudder, midship, and bow at three depth zones including close to the surface (0–1.8 m), mid-depth (1.8–5 m), and bottom (>5 m) and two substratum orientations (vertical and horizontal), all in a randomized block design. Each species was identified to the lowest possible taxon and assigned a relative abundance in each sample. Photographs were taken at various points on the hull to provide an overview of the degree of development of the fouling communities present. The known distributions of taxa identified to species were determined using the available taxonomic literature. This simple zoogeographic analysis was undertaken to determine which, if any, of the species present on the hull were already in Hawai'i, and if not, which could become successful colonists if the vessel was brought into Hawaiian waters.

After a 9-day sojourn at Astoria, Oregon, 19.5 km up the Columbia River, the *Missouri* was towed directly to Pearl Harbor, Hawai'i, arriving at its berth on 22 June 1998. Within 1 hr of docking, the first underwater reconnaissance and sampling program was undertaken. The rationale for sampling as soon as possible is that motile benthic species are opportunistic and will rapidly colonize any "open" habitats. Any species on the hull could have originated from one of four sources: Puget Sound, the Columbia River, the open ocean across which the ship was towed, or from Pearl Harbor itself. Local colonists on the hull from Pearl Harbor would serve to confound separation of species that originated from Puget Sound and the high seas pelagic realm in any samples taken.

The underwater survey sampled both live and dead material in the same portions of the hull as sampled in Bremerton. Sampling focused on areas where fouling organisms were seen; areas appearing to be free of all fouling were not scraped. Sampling of these materials included both specifically catching (as with motile settling crab megalops) individual organisms and placing them in containers, and scraping attached dead materials on the hull into 0.5-mm mesh bags, the contents of which were later preserved, stained with rose bengal, and sorted in the laboratory. An effort was made to standardize the area scraped ($\sim$1000 cm^2) for each sample. Samples were placed in trays with seawater as they were collected, and observations were made for any signs of life (i.e., movement such as adductor muscle response) before they were preserved in labeled vials. Preserved samples were sorted in the laboratory for stained material (rose bengal is taken up by tissue). All collected specimens were opened (including remaining sabellid tubes, bivalves, and moribund tunicates) to examine remaining internal structures (e.g., setae, adductor muscles, etc.). All live material was sorted and identified to the lowest taxon possible.

The underwater survey of the ship's hull, which commenced within an hour of docking in Pearl Harbor, covered the length of the starboard side of the hull (270 m) from the ship's midline or keel to the water's surface, comprising more than 4500 m^2 of the hull's outer surface.

A second sampling of the fouling communities on the hull was carried out 83 days after the arrival of the *Missouri* in Pearl Harbor to determine the condition of any remaining fouling originating from elsewhere. This sampling effort again collected live and dead fouling material using the same methods as above. The objective of this effort was to determine if any of the previously identified non-Hawaiian species arriving on the vessel had survived.

Before committing the *Missouri*'s hull to treatment by exposure to freshwater, several questions had to be answered regarding the conditions of salinity and duration of exposure that would have the desired effect, and where those conditions could be found during the time of year the vessel would be towed to its new berth. Freshwater causes mortality in marine species by osmotic dis-

ruption of cells. However, many fouling species are euryhaline, tolerant of a range of salinity conditions often found in estuarine environments, and individuals within species may also exhibit variation in tolerance to a range of salinities. There is no absolute salinity value that assures mortality of all individuals present, but both the absolute change in salinity as well as the rate of that change are important factors in mortality (Dobson 1946, Benson et al. 1973).

To treat the hull, exposure to near-freshwater conditions to a depth of about 10 m (maximum hull depth) was needed. Salinity as it relates to tide and volume of freshwater input at the proposed berth on the Columbia River was evaluated over several days using a YSI temperature/conductivity/salinity meter.

RESULTS

Observations made in Bremerton where the ship was moored indicated that fouling communities on the *Missouri* were well developed and particularly dense at the turn of the bilge and bottom, creating a layer 30 cm in thickness. These communities had developed in salinities ranging from 33 to 35 parts per thousand (ppt). The starboard side of the ship was closest to the dock. Dominant species included the white plumose anemone *Metridium senile* (to 45 cm in height), sabellid or featherduster tubeworms (*Pseudopotamilla* spp.), mussels (*Mytilus* cf. *edulis* spp. complex), oysters (*Crassostrea* spp.), and barnacles (*Balanus glandula/crenatus* complex). Porifera (sponges), Ectoprocta (Bryozoa), and Urochordata (tunicates) were also well represented. Fouling communities on the vessel's hull were best developed below 5 m depth.

Ten samples collected in Bremerton from the vessel's hull included 116 taxa. Most of these taxa (83%) were rare in the samples; the remainder were more common. Twelve phyla were represented among the 116 taxa, with polychaetes being most species-rich (Annelida: 36 taxa) followed by crabs and shrimps (Arthropoda: 21 taxa) and gastropods and bivalves (Mollusca: 13 taxa). Seventy-six taxa (65.5%) were identified to species, 22 (19.0%) to the generic level, and 18 (15.5%) to a taxon above the generic level (Table 1). Eleven of the 76 species (14.5%) are known from Hawaiian waters and are listed in Table 2; all of these are considered to be introduced, cryptogenic (most probably introduced but

TABLE 1

MAJOR TAXA AND THOSE IDENTIFIED TO SPECIES AMONG THE 12 PHYLA IN THE FOULING COMMUNITIES SAMPLED ON THE HULL OF THE USS *Missouri* IN BREMERTON, WASHINGTON

PHYLUM	NO. OF MAJOR TAXA	NO. OF SPECIES IDENTIFIED
Protozoa	1	1
Porifera	4	2
Cnidaria	8	3
Platyhelminthes	3	1
Nemertea	5	3
Nematoda	1	0
Annelida	36	33
Mollusca	13	10
Arthropoda	22	11
Ectoprocta	9	5
Echinodermata	4	3
Urochordata	11	4
Total	116	76

TABLE 2

SPECIES COLLECTED FROM THE HULL OF THE USS *Missouri* IN BREMERTON, WASHINGTON, THAT ARE ALSO KNOWN FROM HAWAIIAN WATERS AS GIVEN IN THE CITED LITERATURE

Phylum Annelida (Segmented worms)
- *Capitella capitata* hyperspecies (Bailey-Brock 1987)
- *Platynereis bicanaliculata* (Bailey-Brock 1987)
- *Podarke pugettensis* (Bailey-Brock 1987)
- *Serpula vermicularis* (Bailey-Brock 1987, Coles et al. 1997)
- *Syllis gracilis* (Coles et al. 1997)

Phylum Mollusca (Shells: Bivalves)
- *Hiatella arctica* (Kay 1979)

Phylum Arthropoda (Crabs, shrimps, and allies)
- *Balanus crenatus* (Coles et al. 1997)
- *Corophium ascherusicum* (Coles et al. 1997)
- *Corophium baconi* (Coles et al. 1997)

Phylum Ectoprocta (Bryozoans)
- *Bowerbankia gracilis* (Soule et al. 1987)
- *Schizoporella unicornis* (Soule et al. 1987, Coles et al. 1997)

origin uncertain), or to have cosmopolitan distributions.

Zoogeographic analysis was focused on taxa identified to species. Of the 76 taxa so identified, four patterns were noted. Eleven are known from Hawaiian waters; 17 have known distributions outside the Pacific Northwest that follow one of three patterns: (1) known from the Pacific Northwest south to California, (2) known from the Pacific Northwest and Britain in the Atlantic, or (3) known from the temperate-boreal North Pacific rim and/or from the temperate-boreal North Atlantic rim. The remaining 48 species are known from the Pacific Northwest. None of these known distributions includes subtropical-tropical waters.

Salinity profiles at Astoria in January 1998 showed that salinity varied with the tide and depth. A distinct halocline rose and fell with the tide, with measured salinities as high as 10 ppt at 10 m; surface salinity was zero. It was anticipated that under spring runoff conditions, the river's flow would rise substantially, which would result in reduced salinity at 10 m depth (P. M. Barrett, Associate Director, Center for Coastal and Land-Margin Research, Oregon Graduate Institute of Science and Technology, pers. comm.). Measurements taken over several days during the berthing in May 1998 found a maximum salinity of 0.5 ppt during high tide at 12.2 m depth, with the lowest portion of the hull exposed to no more than 0.3 ppt, confirming that the hull received close to a total freshwater exposure during the 7 days while moored.

While at Astoria, observations of the hull made from the surface revealed that much of the marine fouling had fallen off after several days of freshwater exposure. Clumps of tubeworms (*Pseudopotamilla* spp.), white plumose sea anemones (*Metridium senile*), and mussels (*Mytilus* cf. *edulis* spp. complex) were seen breaking loose and being carried away as the river flowed toward the sea.

The vessel left the Columbia River on 3 June 1998 and was towed directly to Hawai'i, arriving in Pearl Harbor on the morning of 22 June 1998. Most of the fouling community had disappeared from the starboard side of the hull: large areas, 30–40 m^2, were clear of all obvious fouling although in some open areas the basal points of mussel (*Mytilus* spp.) byssus threads were present. Remnants of the fouling community were still present on areas of the hull not directly exposed to the direct action of water motion, where "patches" of sessile invertebrates ranged in size from about 100 cm^2 to several contiguous square meters. Most of the organisms in these patches were dead; the most obvious species or moribund parts included tubes and setae of sabellid tubeworms (*Pseudopotamilla* spp.), mussel byssus (*Mytilus* cf. *edulis* spp. complex), and barnacle plates (*Balanus glandula/crenatus* complex).

At least 11 live taxa were collected from the hull of the *Missouri* during the 22 June 1998 survey. These taxa included oysters (*Crassostrea gigas* and *Ostrea lurida*), mussels (*Mytilus* cf. *edulis* spp. complex), barnacles (*Balanus glandula/crenatus* spp. complex), stalked barnacles (*Lepas anatifera* and *L. pacifica*), amphipods (*Corophium spinicorne* and *Eogammarus oclairi*), two unidentified species of crab megalops, and unidentified calanoid copepods. The crab megalops were actively recruiting out of the water column to the hull and on to diver's suits and skin during the collection operation. Touch tests on live mussels, oysters, and balanoid barnacles in seawater trays showed slow valve closure and/or little response, suggesting that these animals were severely stressed. Only the calanoid copepods and two amphipod species were active when collected.

Final sampling of biofouling on the hull of the *Missouri* was done 83 days (on 14 September 1998) after its arrival in Pearl Harbor. None of the species previously found alive in the 22 June 1998 sampling effort was alive or present in the final survey; thus the immersion in freshwater was successful in eliminating the threat of a successful alien fouling species introduction.

DISCUSSION

The native or ancestral habitat of an alien species may offer clues as to the probable

chance for successful colonization in a new habitat as well as to its susceptibility to treatment by freshwater immersion. If the physical and biological characteristics of the source habitat are similar to those of the host or recipient habitat, the probability of a successful introduction is greater. Successful invasion by an alien species is greater with those species having more generalized niche requirements than with those with narrower niche tolerances. The temperate fouling community on the *Missouri* was similar to others in the Bremerton area (Greene and Schoener 1982). Other than the 11 introduced, cryptogenic, or cosmopolitan species known from Hawaiian waters, the remaining species identified from the first *Missouri* collection are probably restricted to cooler climates and thus were unlikely to survive in a tropical environment.

There were four probable sources for the live organisms found on the *Missouri*'s hull upon its arrival in Pearl Harbor: four species (or species complexes) from Bremerton in Puget Sound, comprising oysters (*Crassostrea gigas* and *Ostrea lurida*), mussels (*Mytilus* cf. *edulis* spp. complex), and barnacles (*Balanus glandula/crenatus* spp. complex); two species of amphipods, *Corophium spinicorne* and *Eogammarus oclairi,* apparently from the extremely low salinity waters of the Columbia River; two stalked barnacles (*Lepas anatifera* and *L. pacifica*) and unidentified calanoid copepods, probably from the pelagic or open ocean environment; and from the waters of Pearl Harbor, two unidentified species of crab larvae (megalops) and possibly the calanoid copepods.

Several species may be eliminated from the assessment of potential vessel-colonizing species because they are already known from Hawaiian waters. This group includes *Crassostrea gigas*, *Lepas anatifera*, and the two unidentified species of crab larvae. *Crassostrea gigas* was introduced to Hawai'i in the 1920s and 1930s (Brock 1960, Kay 1979), and *Lepas anatifera* was recorded by Edmondson (1946).

Recruits to the vessel's hull in Bremerton and alive at the time of arrival in Pearl Harbor all showed very weak and slow response to touch (valve or plate closure). All of these sessile species have probably had many opportunities to be naturally carried to Hawaiian shores via floating debris as well as on ships' hulls, and their absence in the known Hawaiian fauna suggests that the local ecological conditions are not appropriate for their survival. The 14 September 1998 resurvey of the hull confirmed this point. For example, *Mytilus edulis* found on drifting material in Hawai'i and held at the Hawai'i Institute of Marine Biology under normal Hawaiian marine winter water temperatures survived for approximately 4 months, but with the onset of higher summer water temperatures quickly succumbed (R. B., pers. obs.).

Species that recruited to the hull while the ship was in transit across the Pacific probably do not represent much of a threat as colonizing alien species because these same species are found attached to floating debris that routinely washes ashore in Hawai'i and is often from the Pacific Northwest (spruce logs, etc.). These pelagic species must have had many previous opportunities to become established and have not. This group includes the stalked barnacle (*Lepas pacifica*) and unidentified calanoid copepods.

The final group of species considered here probably recruited to the hull of the *Missouri* while she was in the low salinity and fresh waters of the Columbia River. Two amphipod species, *Corophium spinicorne* and *Eogammarus oclairi*, are known from low salinity and fresh waters of the Pacific Northwest (Barnard 1954, Otte 1975, Bousfield 1979). These two species survived the transoceanic crossing, were relatively common on the hull of the ship, and swam actively, but we did not find any individuals among the 175 *C. spinicorne* and 54 *E. oclairi* examined that appeared to be reproducing. Many amphipods have relatively short life spans and reproduction may be a near-continuous event, especially in tropical species. The lack of ovigerous females in these Columbia River species could be due to the high salinity and/or high temperature environment in Pearl Harbor. Normal surface salinities around Ford Island in Pearl Harbor where the *Mis-*

souri is docked are 29–36 ppt except during times of exceptional rainfall (Evans 1974). The 14 September 1998 survey failed to find either Columbia River amphipod species in the fouling community. Individuals of a species may colonize a new habitat, but if reproduction does not occur, these colonists will disappear. As with the other live species on the hull of the *Missouri* and identified from the west coast of North America, the argument may be made that these two amphipod species have probably had ample opportunity to colonize the Hawaiian Islands in the past by natural means (via logs and other floating debris) as well as by anthropogenic means (i.e., ballast water and/or on the hulls of vessels).

The success of the 9-day exposure to freshwater in ridding the *Missouri* of its well-developed marine fouling communities may be related to a number of factors including the original environment of the vessel, the conditions in the estuary to which it was towed, and conditions at its ultimate destination. As a treatment to prevent introduction of potential alien nuisance species, mortality of the organisms, but not necessarily their removal, is required. For this purpose, the absolute and relative salinity change, rapidity of that change, and duration of exposure to freshwater are primary influencing factors. For the conditions experienced by the *Missouri*, these factors appear to have been sufficient to substantially reduce the density of organisms on the hull.

The hull of the *Missouri* had been treated with ablative antifouling paint in her 1993 dry-docking. To achieve improved propulsion efficiency, the attached organisms must be entirely removed from the hull in an oceangoing vessel. In the 22 June 1998 survey, fouling remaining on the hull was greatest on the downcurrent side behind obstacles protruding from the ship's hull that created a "lee" or quiet water situation. The degree to which the *Missouri*'s ablative hull coating contributed to this occurrence is not clear. Ablative coatings are "self-polishing" paints in which a biocide (organotin) is combined with a polymer to form an unstable material that dissolves at the surface providing a controlled release of toxin, the rate of which depends, among other factors, on the flow of water over the hull (Swain and Zborowski 1989). The fact that the distribution of fouling organisms on the *Missouri* was highest, up to 80%, on portions of the hull sheltered from the tidal currents at its berth in Bremerton and lowest, 20% or less, in the more exposed upper areas of the hull, suggests that the ablative paint was at least partially effective while the vessel was at berth. After the 9-day exposure to freshwater, the majority of fouling organisms are presumed to have been killed. The ablative effect may have contributed to the release from the hull of attached hard-shelled remains of such organisms as barnacles and mussels as a result of being towed to Hawai'i at an approximate speed of 4 to 7 knots (7.4–13.0 km/hr).

Shipping between Hawai'i and the Pacific Northwest has been occurring routinely since the 1880s, with lumber and salted salmon coming to Hawai'i. Ships on their return to the west coast carried sugar to San Francisco (Scott 1968). In more than 100 yr of commerce, there has been considerable opportunity for the transport of nonindigenous species from the Pacific Northwest to Hawaiian waters. Mariners are well aware that marine growth (fouling communities) on the hulls of their vessels greatly impacts the time and/or energy consumed in moving their vessels from one harbor to another. Accordingly, marine growth is usually controlled, and most commercial vessels coming from the Pacific coast probably have relatively clean hulls with little obvious fouling. For an introduction to be successful, all it takes is transport of one pair (or an ovigerous female) from donor site to new host habitat. None of the species that arrived alive on the hull of the *Missouri* is rare or unusual, thus the probability that they have been transported to Hawai'i in the past is high in light of the relatively long history of shipping between the temperate Pacific west coast and Hawai'i. Because none of these species has been recorded as having successfully recruited to Hawaiian waters, the probability that the ecological conditions are not appropriate for these species is high. Thus none of

them would be expected to survive and apparently none have.

CONCLUSIONS

Is the method described herein of general value in reducing the potential for the introduction of alien hull-fouling organisms into other nonnative ports? The U.S. Coast Guard evaluates that potential based on the length of time that an arriving vessel has been laid up before transit to a given port, and in Hawai'i a number of such vessels have been turned away (Capt. Frank Whipple, Marine Safety Office, Ninth Coast Guard District, Honolulu, pers. comm.). Where vessels are laid up in an essentially marine environment, the method described herein is likely to be effective. Where an arriving vessel is laid up in a location with an environment similar to that of Hawai'i, the risk of introduction is high and hull treatment is an important risk-reducing strategy. The cost of the detour from Bremerton, Washington, to Astoria, Oregon, for the 9-day fresh and brackish water exposure was about $100,000. The cost to dry-dock the *Missouri* would have been in excess of $1 million. The detour to Astoria not only eliminated the threat of an alien species introduction, but also saved money by avoiding the cost and environmental risk associated with mechanical bottom cleaning.

A low-cost solution is more likely to be applied in these cases than an expensive one. The costs of movement to, and berthing in, a freshwater environment as well as the revenues lost due to the lay-up period need to be considered against the cost of alternatives such as cleaning in place or dry-docking. Where these conditions compare favorably, freshwater immersion may be an effective means for reducing the potential for introduction of alien aquatic nuisance species.

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